

NUCLEONICA: Decay Engine J. MAGILL

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Decay Engine

Some theory

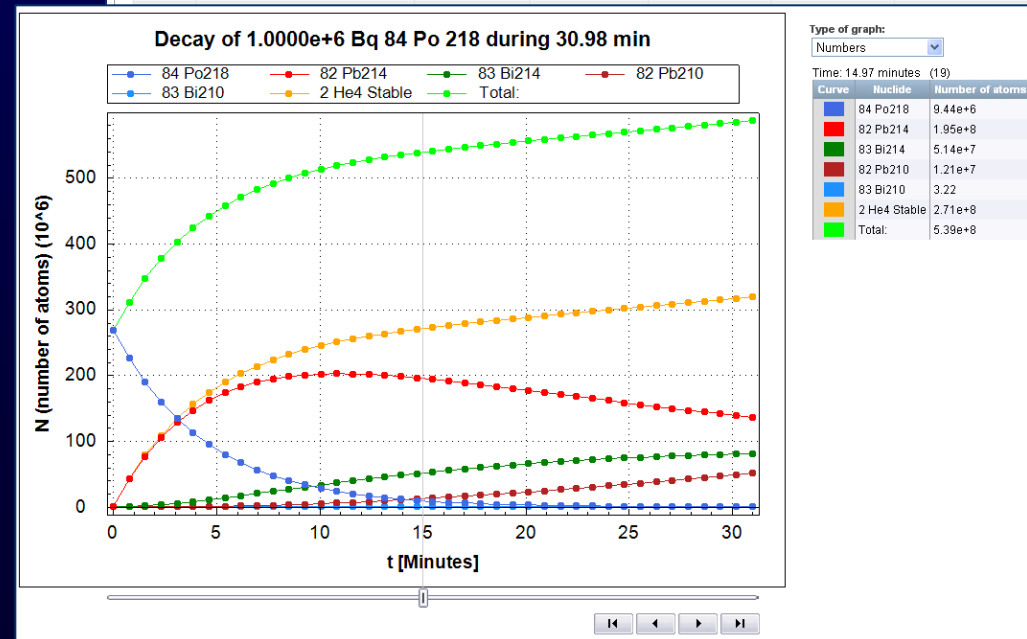
Launching Decay Engine

Performing calculation with default settings

Exploring calculation results

Selecting options

Plotting results



Modern Alchemy: Discovery of transmutation, (Soddy 1901)

In 1901, twenty-four year-old chemist Frederick Soddy and Ernest Rutherford were attempting to identify a mysterious gas that wafted from samples of radioactive thorium oxide. They suspected that this gas—they called it an “emanation”—held a key to the recently discovered phenomenon of radioactivity. Soddy had passed the puzzling gas over a series of powerful chemical reagents, heated white-hot. When no reactions took place, he came to a startling realization. As he told his biographer many years later....

‘I remember quite well standing there transfixed as though stunned by the colossal import of the thing and blurting out- or so it seemed at the time: “Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon gas“. Rutherford’s reply was typically aware of more practical implications, “For Mike’s sake, Soddy, don’t call it *transmutation*. They’ll have our heads off as alchemists“

*quoted in *Pioneer*, pp 83-84



Frederic Soddy



Joseph Wright (1734-1797)

Simple radioactive decay..

Basic equation first identified by Rutherford

$$dQ/dt = -kQ \quad (1)$$

Q is the number of atoms, k is the decay constant (probability per unit time that a nucleus will decay):

$$k = \ln 2 / \tau$$

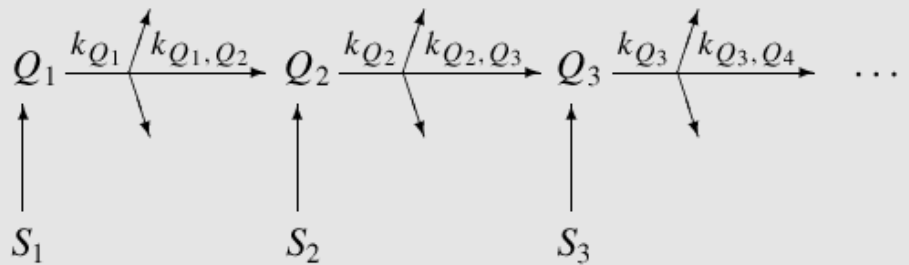
where τ is the half-live. Solution of Eq.1...

$$Q(t) = Q(0) e^{-kt} \quad \text{or} \quad Q(t) = Q(0) 2^{-t/\tau}$$

Activity..

$$A(t) = k Q(t)$$

Successive radioactive decay with branching and source terms



The differential equations governing the above processes:

$$\begin{aligned} dQ_1/dt &= S_1 - k_{Q_1} \cdot Q_1, \\ dQ_2/dt &= S_2 + k_{Q_1, Q_2} \cdot Q_1 - k_{Q_2} \cdot Q_2, \\ dQ_i/dt &= S_i + k_{Q_{i-1}, Q_i} \cdot Q_{i-1} - k_{Q_i} \cdot Q_i, \\ dQ_n/dt &= S_n + k_{Q_{n-1}, Q_n} \cdot Q_{n-1} - k_{Q_n} \cdot Q_i, \end{aligned}$$

Mr. Bateman, Solution of a system of differential equations, etc. 423

The solution of a system of differential equations occurring in the theory of radio-active transformations. By H. BATEMAN, M.A., Trinity College.

[Read 21 February 1910.]

1. It has been shown by Prof. Rutherford * that the amounts of the primary substance and the different products in a given quantity of radio-active matter vary according to the system of differential equations,

$$\left. \begin{aligned} \frac{dP}{dt} &= -\lambda_1 P \\ \frac{dQ}{dt} &= \lambda_1 P - \lambda_2 Q \\ \frac{dR}{dt} &= \lambda_2 Q - \lambda_3 R \\ \frac{dT}{dt} &= \lambda_3 R - \lambda_4 T \\ &\dots\dots\dots \end{aligned} \right\} \dots\dots\dots (1).$$

denote the number of atoms of the primary substance and the various products which are present at time t . Prof. Rutherford has worked out the various cases in which the products in addition to the primary substance, but as if the results may be extended to any without much labour.

The straightforward method is unsymmetrical, the results of the calculations are needed in which are being carried on in radio-activity, but it is worth while to publish a simple and direct method of obtaining the required formulae. Let us assume a set of auxiliary quantities $p(x)$, $q(x)$, $r(x)$, $s(x)$, ... on a variable x and connected with the quantities P , Q , R , T , ... by the equations,

$$p(x) = \int_0^\infty e^{-xt} P(t) dt, \quad q(x) = \int_0^\infty e^{-xt} Q(t) dt, \dots\dots\dots (2).$$

It is easily seen that

$$\begin{aligned} \int_0^\infty e^{-xt} \frac{dP}{dt} dt &= -P(0) + x \int_0^\infty e^{-xt} P(t) dt \dots\dots\dots (3), \\ &= -P_0 + xp, \end{aligned}$$

* Radio-activity, 2nd edition, p. 582.



H. Bateman

Exact solution:

$$Q_n(t) = \sum_{i=1}^{i=n} \left[\left(\prod_{j=1}^{j=n-1} k_{j,j+1} \right) \times \sum_{j=i}^{j=n} \left(\frac{Q_i(0) e^{-k_j t}}{\prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)} + \frac{S_i (1 - e^{-k_j t})}{k_j \prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)} \right) \right]$$

For $S_i = 0$:

$$Q_n(t) = \prod_{j=1}^{j=n-1} k_{j,j+1} \sum_{j=i}^{j=n} \frac{Q_i(0) e^{-k_j t}}{\prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)}$$

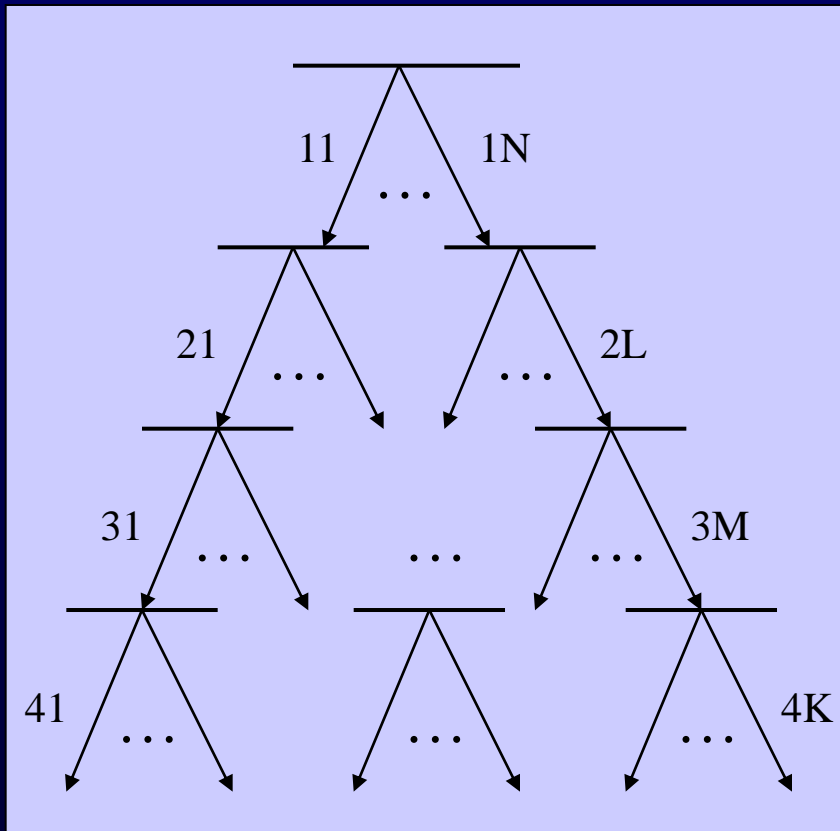
First few terms...

$$Q_1 = Q_1(0) e^{-k_1 t}$$

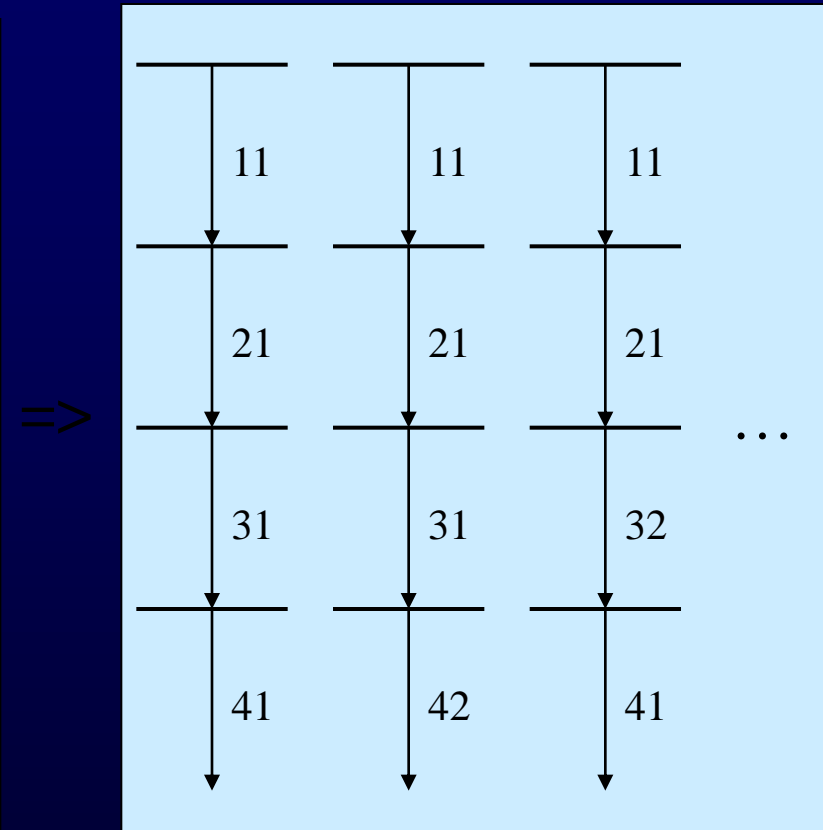
$$Q_2 = k_{1,2} \left\{ \frac{Q_1(0) e^{-k_1 t}}{k_2 - k_1} + \frac{Q_1(0) e^{-k_2 t}}{k_1 - k_2} \right\}$$

$$Q_3 = k_{1,2} k_{2,3} \left\{ \frac{Q_1(0) e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{Q_1(0) e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{Q_1(0) e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)} \right\}$$

Decay Tree



Linear Chains



$$\text{Prod}_1 = \text{BR}_{11} \text{BR}_{21} \text{BR}_{31} \text{BR}_{41}$$

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nucleonica ... web driven nuclear science

Applications My Preferences Help New Alerts

- Nuclide Explorer
- Mass Activity Calculator
- Decay Engine**
- Dosimetry and Shielding
- Range and Stopping Power
- webKORIGEN
- Universal Nuclide Chart
- Transport and Packaging
- Nuclide Mixtures
- Nucleonica Scripting
- Library Creation
- Extended Graph Module
- Physical Constants
- Nuclide Datasheet
- Radiations
- Fission Yields
- Nuclear Data Retrieval
- Nuclear News
- Conference Calendar

Application Centre

- » Mass Activity Calculator
- » **Decay Engine**
- » Dosimetry & Shielding
- » Range & Stopping Power
- » webKORIGEN
- » Universal Nuclide Chart
- » Transport & Packaging
- » Nuclide mixtures
- » Nucleonica Scripting
- » Library creation for 3rd party software
- » Radiological Dispersion Module
- » Extended Graph Module

Data Centre

- » Physical Constants
- » Nuclide Datasheets
- » Nuclide Derived Data
- » Average Cross Sections
- » Radiations
- » Prompt Gamma
- » Fission Yields

Knowledge Centre

- » Nuclear News
- » Reading room
- » Useful Weblinks
- » Ask An Expert
- » Element Information
- » Conference Calendar

Welcome, Andrey

Edit Preferences
MyCommunity Portal

My Last Nuclides

- 92 U235
- 43 Tc90
- 52 Te118
- 34 Se81 m
- 73 Ta155

My Nuclide Mixtures

- Transuramics in 1 ton Spent Fuel (4.2% enriched, %50GWd/t, 6 years cooling)
- Cs137+Ba137m
- U232+Co60
- Test_Source_1

My Sources

No sources selected yet

My Messages

- Maintenance Work
- Maintenance Work
- Maintenance Work
- NAMLS-9 International Conference on Nuclear Analytical Methods in the Life Sciences
- Request for photos of non-stable elements

» View

User Alerts

To launch the Decay Engine

click on Decay Engine in the Application Center list.....

or

choose Decay Engine from the Applications dropdown list....

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Views Applications My Preferences Help New Alerts

Select

Element: Mass:

Po 218

Zoom

View: 5

Select colour theme:

Karlsruhe

☒ alpha ☒ beta- ☒ beta+ ☒ IT ☒ n ☒ SF ☒ p ☒ ec ☒ CE

☒ stable

All None

Background

Rn216 45 μ s	Rn217 540 μ s	Rn218 35 ms	Rn219 3.96 s	Rn220 55.8 s	Rn221 25 m	Rn222 3.82 d
At215 100 μ s	At216 300 μ s	At217 32.3 ms	At218 1.5 s	At219 54 s	At220 3.71 m	At221 2.3 m
Po214 1.6E2 μ s	Po215 1.78 ms	Po216 150 ms	Po217 1.47 s	Po218 3.1 m	Po219 2 m	Po220 40 s
Bi213 45.59 m	Bi214 19.9 m	Bi215 36.9 s 7.4 m	Bi216 2.17 m	Bi217 1.84 s		
Pb212 10.64 h	Pb213 10.2 m	Pb214 26.8 m	Pb215 36 s			

130 131 132 133 134 135 136

Ground state: 3127 nuclides from 3127 Metastable: 769 nuclides from 769 Total: 3896 nuclides from 3896

To launch the Decay Engine

select nuclide of interest in the Nuclide Explorer page.....

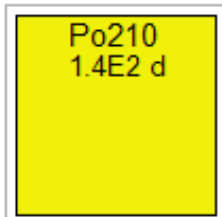
then

click right mouse button over it

and

choose Decay Engine from the list, which will appear

.....



Decay engine 84 Polonium

Current Chart: Karlsruhe

Element

Po

Mass

210



Decay Engine

Options

Decay Tree

Mixture details

Time Unit

Years

Decay Time

3.78893

Starting quantity

1.0000e+6

Final quantity

???

Unit

Becquerel

Start

Reset

Type of graph:

Activities

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Applications Data Knowledge My Preferences Print Networking Nuclear Science Help New Browser

Po218
3.1 m

Decay engine 84 Polonium

Current Chart: Karlsruhe

Element: Po Mass: 218 Mixture selector

Decay Engine Options Decay Tree Mixture details

Time Unit: Minutes Decay Time: 30.98

Starting quantity: 1.0000e+6 Final quantity: 1.54E+05 Unit: Becquerel

Start Reset Create Nuclide Mixture

Calculation details

Number of timesteps: 40 Accuracy Factor: 0.01 Distance (cm): 100 Number of linear chains: 1

Plot	Parent-Daughters	Half-life	Decay	N(Atoms)	A(Bq)	Disintegrations	β^- anti v
<input checked="" type="checkbox"/>	84 Po218	3.1 m	$\alpha; \beta^-$	2.62E+05	9.77E+02	2.68E+08	5.09E+04
<input checked="" type="checkbox"/>	82 Pb214	26.8 m	β^-	1.36E+08	5.85E+04	1.32E+08	1.32E+08
<input checked="" type="checkbox"/>	83 Bi214	19.9 m	$\beta^-; \alpha; \beta^-; \alpha$	8.11E+07	4.71E+04	5.10E+07	5.10E+07
<input checked="" type="checkbox"/>	84 Po214	1.6E2 μ s	α	1.11E+01	4.71E+04	5.10E+07	0
<input checked="" type="checkbox"/>	82 Pb210	22.17 y	$\beta^-; \alpha$	5.10E+07	5.05E-02	3.20E+01	3.20E+01
<input type="checkbox"/>	83 Bi210	5.01 d					
<input type="checkbox"/>	84 Po210	1.4E2 d					
<input type="checkbox"/>	82 Pb206 Stable	stable					
<input type="checkbox"/>	2 He4 Stable	stable					
<input checked="" type="checkbox"/>	Total:						

Decay of 1.0000e+6 Bq 84 Po 218 during 30.98 min

Type of graph: Numbers

Time: 14.07 minutes (18)

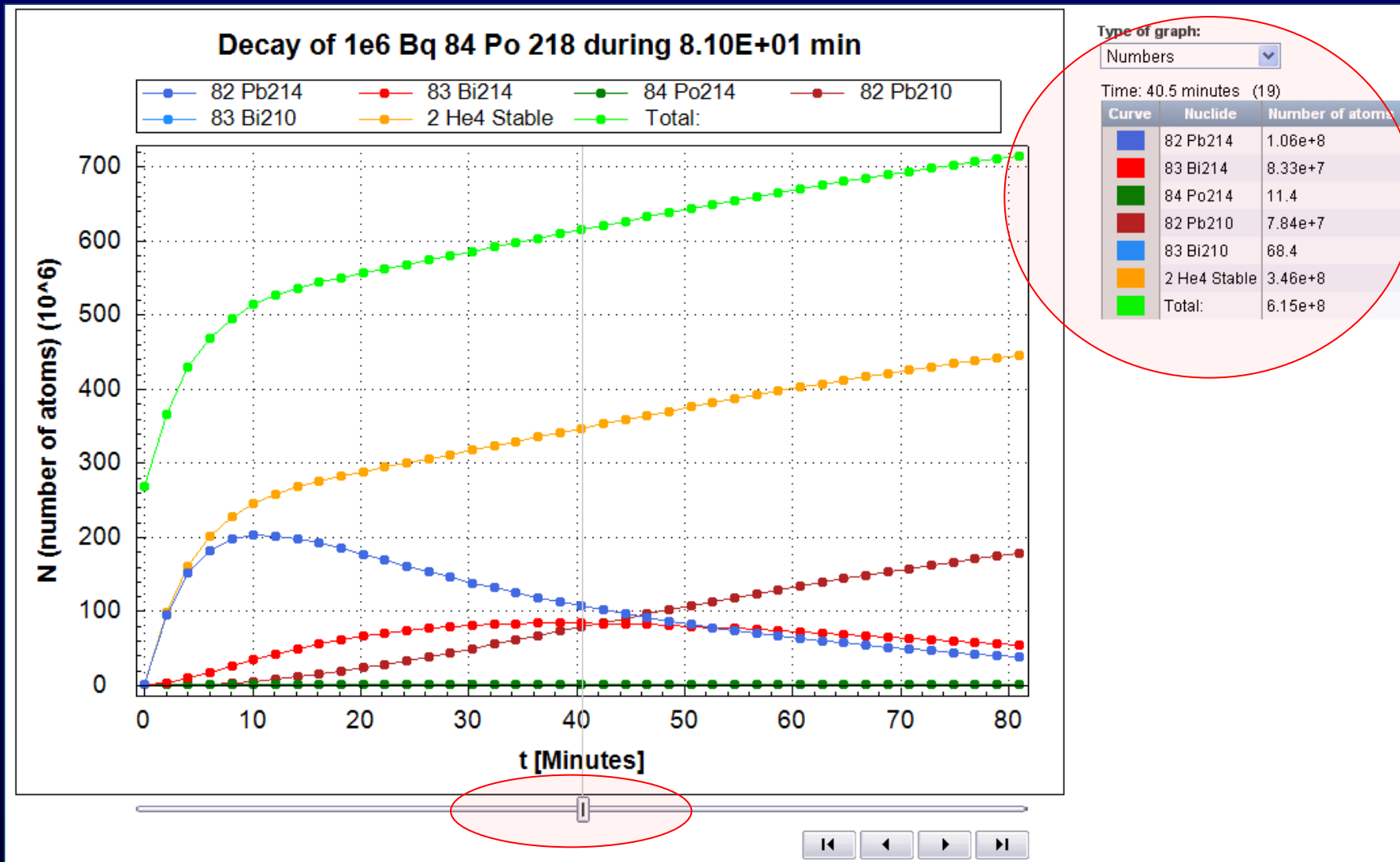
Curve: 84 Po218 82 Pb214 83 Bi214 84 Po214 2 He4 Stable Total

Legend:

- 84 Po218: 9.44e+05
- 82 Pb214: 1.95e+08
- 83 Bi214: 5.14e+07
- 84 Po214: 1.21e+07
- 82 Pb210: 3.22
- 2 He4 Stable: 2.71e+08
- Total: 5.39e+08

Start a calculation using default values....

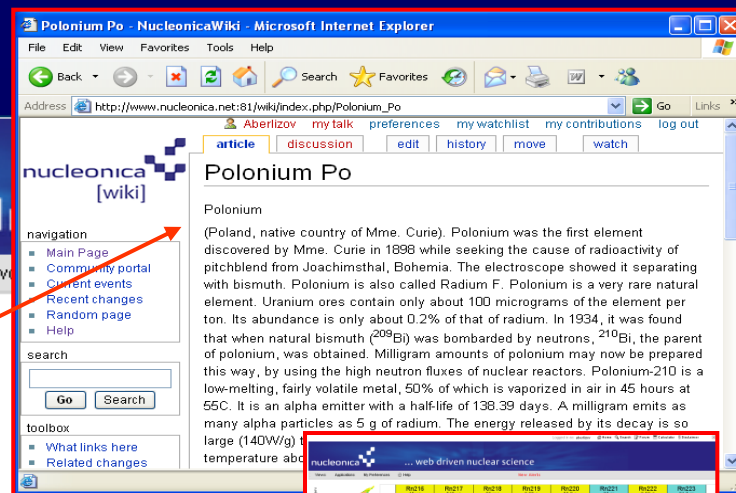
Slider control for easy reading graph values...



Nuclide selection tools

Po	218
Pr	198
Pt	199 m
Pu	200
Ra	201
Rb	201 m
Re	202
Rf	203
Rg	203 m
Rh	204
Rn	205
Ru	205 m
S	206
Sb	207
Sc	207 m
Se	208
Sg	210
Si	211
Sm	211 m
Sn	212
Sr	212 m
Ta	213
Tb	214
Tc	215
Te	216
Th	217
Ti	218
Tl	219
Tm	220
U	

Element Info in Nucleonica wiki



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Po218 3.1 m

Decay engine

84 Polonium

Current Chart: Karlsruhe

Element: Po Mass: 218

Decay Engine Options Decay Tree Mixture details

Time Unit: Minutes Decay Time: 30.98

Starting quantity: 1.0000e+6 Final quantity: ??? Unit: Becquerel

Start Reset

Type of graph: Activities

Set time

Set quantity

Select the value to be plotted on a graph

Set the number of timesteps. To plot a graph up to 40 timesteps can be used.

Set the accuracy of the calculation. Default value 1E-2 gives at least the main chain. Min. **Zero** value gives all chains!



Calculation details

Number of timesteps: 40

Accuracy Factor: 0.01

Distance (cm): 100

Number of linear chains: ???



Decay Engine 84 Polonium

Actual Chart: Karlsruhe

Element: Mass:

Po

218



Nuclide Mixtures Selector

Decay Engine Options

Quantity: Grams 1

Accuracy Factor: 0

Time: Days 2.15E-02

Number of timesteps: 10

Number of chains: 23

Start Start in background Reset Show Details Create Nuclide Mixture

Parent+Daughters	Half-life	BR	Decay	N(atoms)	M(g)	A(Bq)
Total:				2.76E+21	9.78E-01	1.58E+18
82 Pb214	26.8 m	1	β-	1.40E+21	4.97E-01	6.03E+17
83 Bi214	19.9 m	0.99979; 2.10E-04; 3.00E-05	β-, α; β-, α	8.36E+20	2.97E-01	4.85E+17
84 Po214	1.6E2 μs	1	α	1.15E+14	4.07E-08	4.85E+17
84 Po218	3.1 m	0.99981; 1.90E-04	α; β-	2.71E+18	9.81E-04	1.01E+16
81 Ti210	1.3 m	0.99993; 7.00E-05	β-, β-, n	1.12E+16	3.91E-06	9.97E+13
85 At218	1.5 s	0.999; 1.00E-03	α; β-	4.19E+12	1.52E-09	1.94E+12
82 Pb210	22.17 y	1; 1.90E-08	β-, α	5.25E+20	1.83E-01	5.20E+11
86 Rn218	35 ms	1	α	9.77E+07	3.54E-14	1.94E+09
83 Bi210	5.01 d	0.999999; 1.32E-06	β-, α	3.29E+14	1.15E-07	5.26E+08
82 Pb209	3.25 h	1	β-	6.70E+12	2.32E-09	3.96E+08
84 Po210	1.4E2 d	1	α	2.39E+11	8.35E-11	1.39E+04
80 Hg206	8.15 m	1	β-	3.64E+06	1.24E-15	5.16E+03
81 Ti206	4.2 m	1	β-	1.34E+06	4.58E-16	3.68E+03
83 Bi209	1.9E19 y	1	α	2.36E+11	8.21E-11	2.73E-16
82 Pb206 Stable	stable			4.80E+06	1.64E-15	0
81 Ti205 Stable	stable			0	0	0

Download



Excel



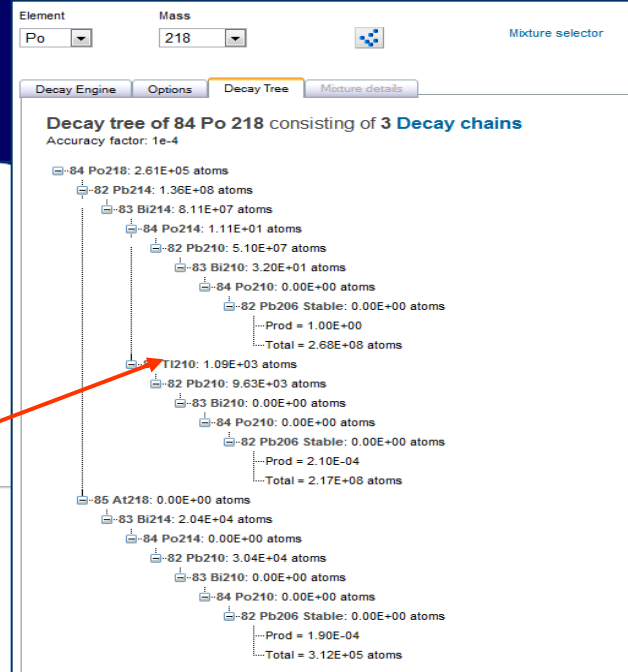
CSV

Separator:

Semicolon (;)



Use field qualifier (")



Click on the column title to arrange the data in ascending /descending order on the parameter chosen

Po218
3.1 m

Decay engine

84 Polonium

Questions, remarks, suggestions can be posted

Current Chart: Karlsruhe

Element

Po

Mass

218

Mixture selector

Decay Engine

Options

Decay Tree

Mixture details

Mode of operation

☒ Time
 ☐ Date

Universal time, UTC

Activate features

☐ Start in Background

Show in grid

<input checked="" type="checkbox"/> Halflives	<input type="checkbox"/> Gamma Emission Rate	<input type="checkbox"/> γ Dose Rate
<input type="checkbox"/> Branching Ratio	<input type="checkbox"/> Spontaneous Fission Rate	<input checked="" type="checkbox"/> Disintegrations
<input checked="" type="checkbox"/> Decay Mode	<input type="checkbox"/> Ingestion Radiotoxicity	<input type="checkbox"/> α particles
<input checked="" type="checkbox"/> Numbers	<input type="checkbox"/> Inhalation Radiotoxicity	<input type="checkbox"/> Released Energy(MeV)
<input type="checkbox"/> Masses	<input type="checkbox"/> Isotopic Power (α)	<input type="checkbox"/> Average Q-Value(MeV)
<input checked="" type="checkbox"/> Activities	<input type="checkbox"/> Isotopic Power ($\alpha+\beta$)	<input checked="" type="checkbox"/> β^- particles / anti ν
<input type="checkbox"/> Activities (α)	<input type="checkbox"/> Isotopic Power ($\alpha+\beta+\gamma$)	<input type="checkbox"/> $ec/\beta^+ / \nu$
<input type="checkbox"/> Activities (β^-)	<input type="checkbox"/> Released Energy(J)	

$\text{Radiotoxicity (Sv)} = \text{Activity} \cdot e(50)$, where
 $e(50)$ - effective dose coefficient, which
 accounts for radiation and tissue weighting
 factors, metabolic and biokinetic information

the heat generated per unit time by
 the decay radiations (W)

Date mode:

Ra226
1.6E3 y

Decay engine

88 Radium

Current Chart: Karlsruhe


Questions, remarks, suggestions can be posted in the [forum](#)

Element

Mass

Ra

226



Mixture selector

Decay Engine


Options

Decay Tree

Mixture details

Starting date /time

13.01.1982 12:15:30



Starting quantity

1.0000e+6

Start


Reset

Type of graph:

Activities

Final date /time

08.06.2012 10:27:20



Time span

30.4015

Years

<< June 2012 >>

Mon	Tu	We	Th	Fr	Sa	Su
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

10

:

27

:

20

OK

Now

Cancel

querel

Calculation details

Number of timesteps:

40

Accuracy Factor:

0.01

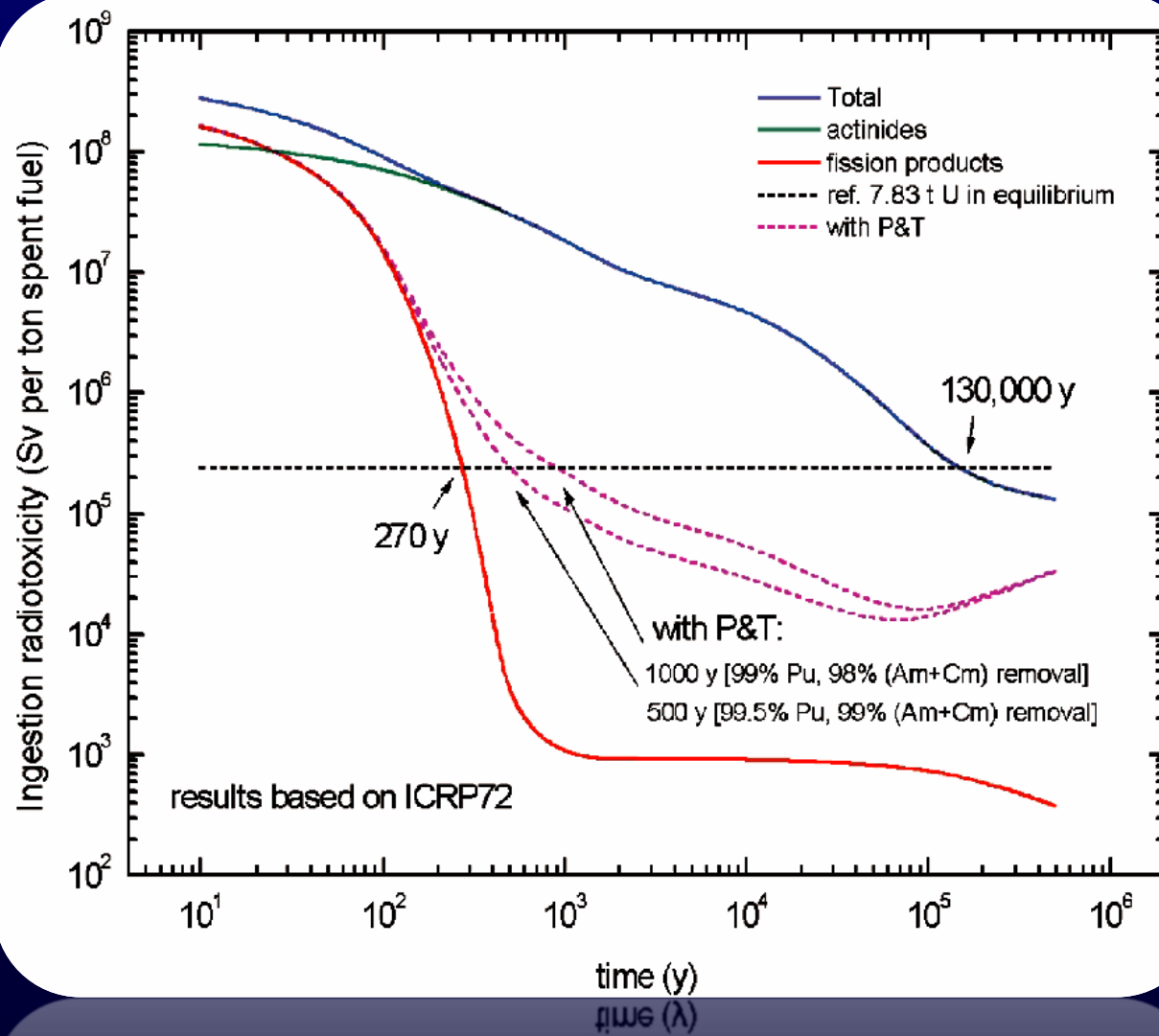
Distance (cm):

100

Number of linear chains:

???





Decay Engine

Some theory

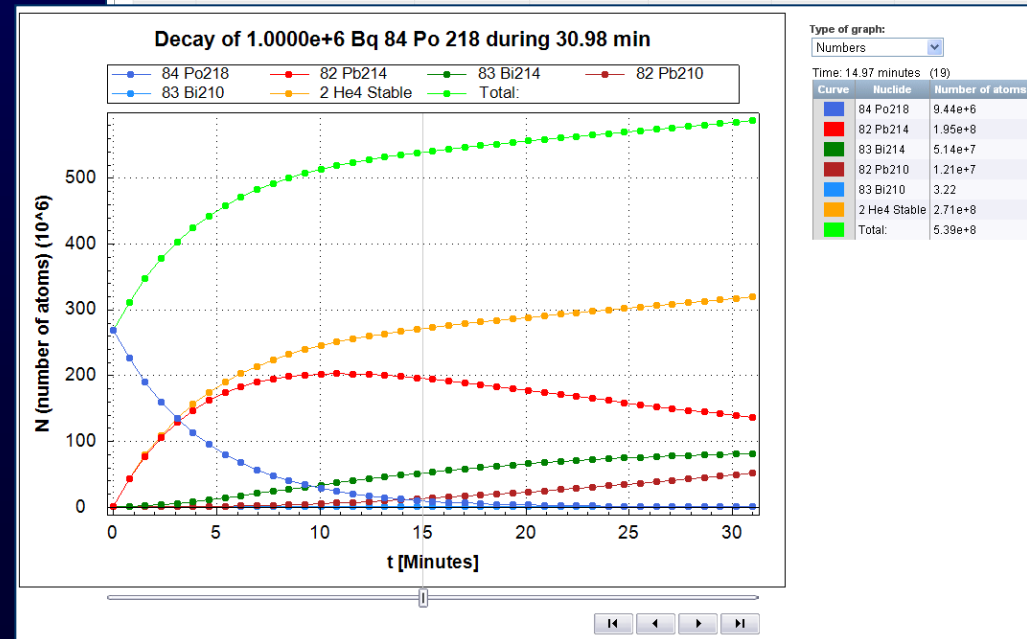
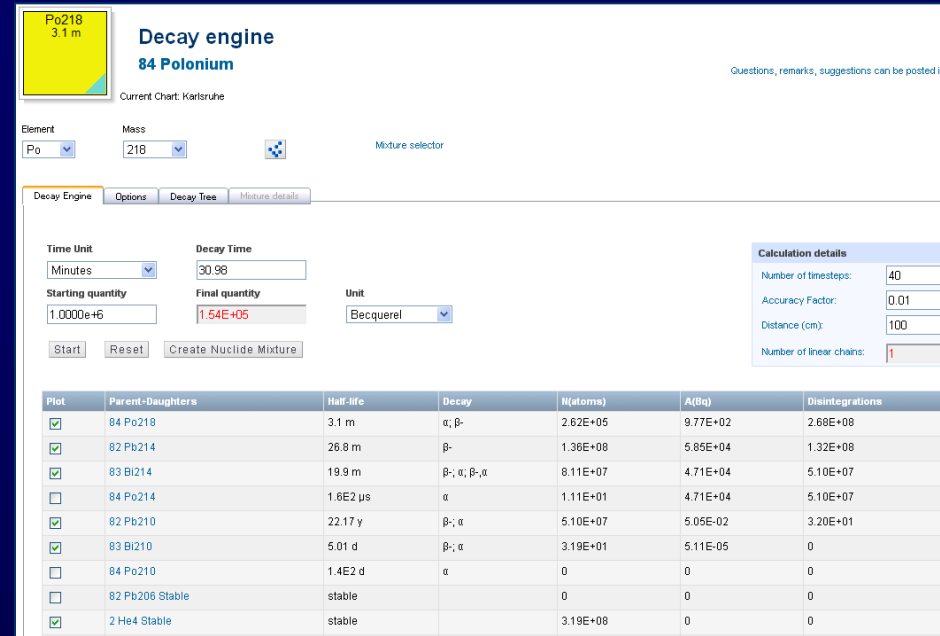
Launching Decay Engine

Performing calculation with default settings

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Thanks!

